

Nuclear physics

Unit - I

(*) Define Radioactivity?

i) Find an expression of radio activity disintegration with time.

(OR)

P.T.

$$N = N_0 e^{-\lambda t}$$

N = number of radioactivity atom at time 't'.

λ = disintegration const.

ii) Find an expression mean life time and half life time?

→ (i) → The heavier nucleus emit's α, β particle's and γ -ray for the stability of the nucleus this phenomenon is known as radioactivity.

For example: ${}_{92}^{235}\text{U}$, ${}_{92}^{238}\text{U}$ radioactive

isotope's of Uranium.

(ii) → Let at time $t=0$, there are N_0 numbers of radioactive nucleus present at the sample.

at time, $t'=t$, the no. of radioactive nucleus equal to N .

the rate of disintegration,

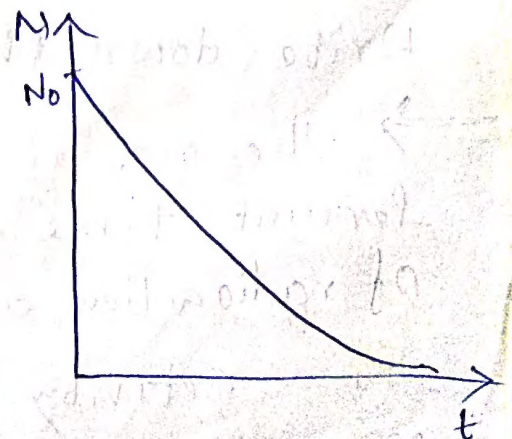
$$\frac{dN}{dt} \propto -N$$

$$2) \frac{dN}{dt} = -\lambda N$$

$$3) \int_{N_0}^N \frac{dN}{N} = -\int_0^t \lambda dt$$

$$4) \ln\left(\frac{N}{N_0}\right) = -\lambda t$$

$$5) \boxed{N = N_0 e^{-\lambda t}}$$



This is also known as disintegration equ.

(iii) \rightarrow The time at which the no. of radioactive atom's become half of the initial no. of radioactive atom is known as half life.

$$\text{at, } t = t_{1/2}, \quad N = \frac{N_0}{2}$$

$$\therefore \frac{N_0}{2} = N_0 e^{-\lambda t_{1/2}}$$

$$\Rightarrow e^{\lambda t_{1/2}} = 2$$

$$\Rightarrow \boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

the time at which no. of particle is become $\frac{1}{e}$ times of its initial no. of particle, this time is known as mean-time.

$$\text{at, time, } t = \tau, \quad N = \frac{N_0}{e}$$

$$\therefore \frac{N_0}{e} = N_0 e^{-\lambda \tau}$$

$$\Rightarrow \boxed{\tau = \frac{1}{\lambda}}$$

$$\therefore \boxed{t_{1/2} = 0.693 \tau} \quad \{ \tau > t_{1/2} \}$$

* Define activity of a radioactive sample?
Write down the unit of activity?

\rightarrow The no. of radioactive disintegration per unit time is known as activity of radioactive sample.

$$\text{activity} = \left| \frac{dN}{dt} \right| = \lambda N$$

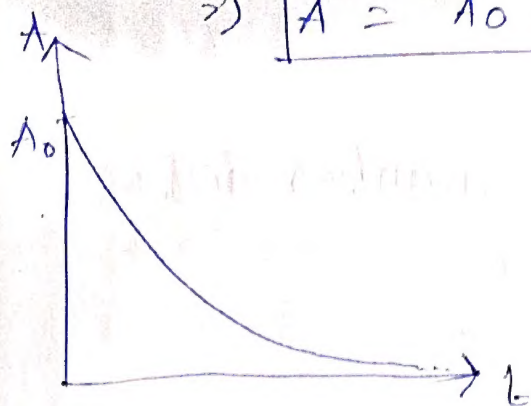
$$\text{as, } N = N_0 e^{-\lambda t}$$

$$2) \lambda N = \lambda N_0 e^{-\lambda t}$$

$A =$ activity at time ' t '.

$$2) \boxed{A = A_0 e^{-\lambda t}}$$

$A_0 =$ activity at time $t = 0$



unit \rightarrow Bq (Bequerel)

1 Bq = 1 DPS [Disintegration per second]

(*) Half life of C^{14} is 12 years.

Find number of C^{14} atom present, after 10 year, if, initially 10 gm of C^{14} is present.

$\rightarrow N_0 = 10 \text{ gm}$

$$t_{1/2} = \frac{0.693}{\lambda} \Rightarrow \lambda = \frac{0.693}{12} = 0.05775$$

$$\therefore N = 10 e^{-0.05775}$$

$$2) N = 10 \times 0.5612$$

$$2) N = 5.612 \text{ gm}$$

$$14 \text{ gm} \longrightarrow 6.022 \times 10^{23}$$

$$\therefore 1 \text{ " } \longrightarrow \frac{6.022 \times 10^{23}}{14}$$

$$\therefore 5.612 \text{ gm} \longrightarrow \frac{6.022 \times 10^{23} \times 5.612}{14}$$

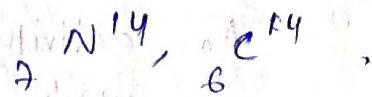
$$= 2.413 \times 10^{23} \text{ atoms}$$

(*) i) Discuss about different types of nuclei.

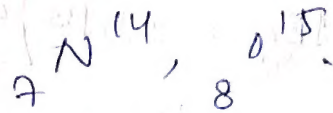
ii) Find the relation between radius of atom and mass number. Hence find the density of ~~atom~~ nucleus.

\rightarrow (i) Isotope: Same no. of proton / atomic no. and different mass no. C^{12}, C^{14}

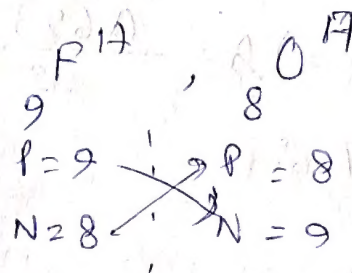
isobar :- Same mass number and differed atomic number / Proton number.



isotone :- Same neutron number different Proton no.



Mirror nucleus :- The neutron no. of 1st nucleus, is equal to proton number of 2nd nucleus and Proton no of 1st nucleus equal to neutron no. of 2nd nucleus.



(ii) The volume of nucleus \propto mass no

$$\frac{4}{3}\pi R^3 \propto A$$

$$\Rightarrow R^3 \propto A$$

$$\Rightarrow \boxed{R = R_0 A^{1/3}}, \quad R_0 \approx 1.4 \text{ fm}$$

$A < 30$

This is the relation between radius $= 1.2 \text{ fm}$ of the nucleus. $A > 30$

and the mass number of the nucleus.

$$\text{density } (\rho) = \frac{\text{Mass}}{\text{Volume}}$$

$$= \frac{A \times m_p}{\frac{4}{3}\pi R^3}$$

$$= \frac{A \times m_p}{\frac{4}{3}\pi R_0^3 A}$$

$$= \frac{3 m_p}{4 \pi R_0^3}$$

$$m_p = 1.67 \times 10^{-27} \text{ kg}$$

$$R_0 = 1.4 \times 10^{-15} \text{ m}$$

$$\approx 1.4 \times 10^{17} \text{ kg/m}^3$$

⑧ Define Mass defect of a nucleus and binding energy of nucleus. Find the relation between them?

→ The difference in mass of a nucleus and its constituent nucleons is called the mass defect of that nucleus.

$$\Delta M = Z m_p + (A - Z) m_n - M(\text{mass of nucleus})$$

The Energy equivalent of the mass defect of a nucleus is called its binding energy.

$$BE = \Delta M c^2$$

⑧ Draw the graph of binding energy per nucleon vs mass number graph. Hence Discuss Different information obtain from this graph?

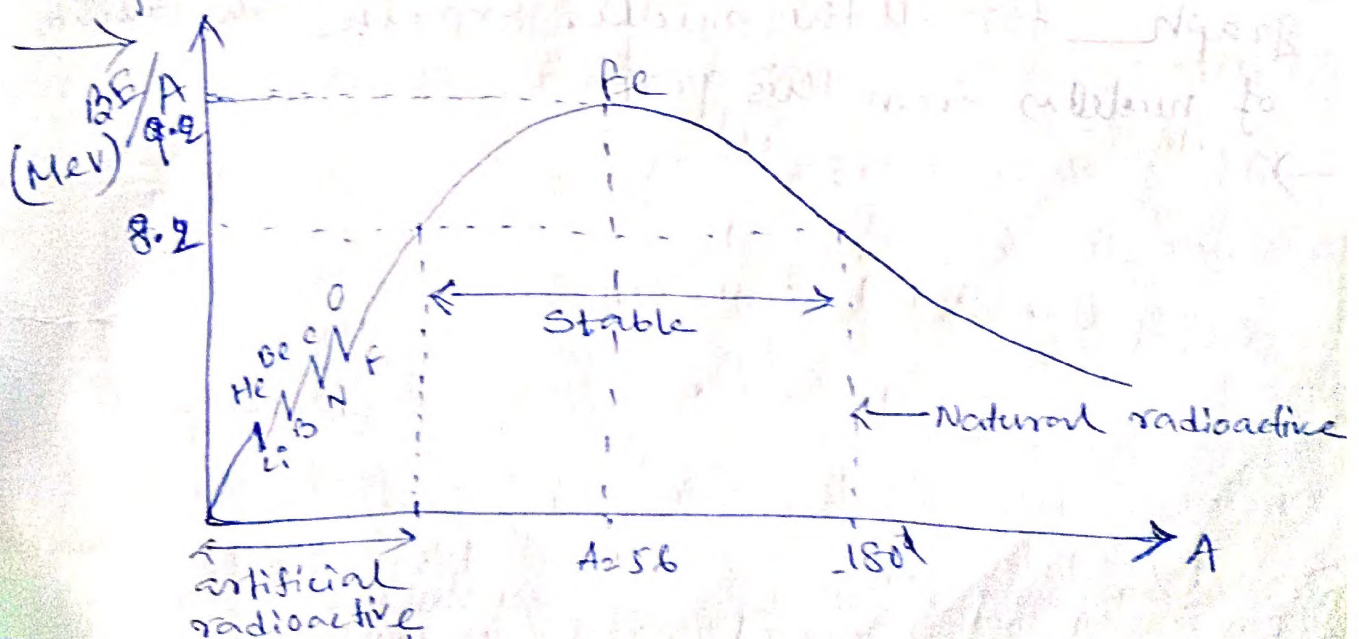


fig. Binding energy per nucleon vs mass no. graph

Various features of BE/A vs A graph:

(i) BE/A increases with mass number and reaches a maximum value of 9.2 MeV per nucleon for mass no. 56 (Fe). After mass no. 56 BE per nucleon decreases with increasing mass number, after mass no. 180 BE/A almost saturated to a value 8 MeV/nucleon .

(ii) For the nuclei, having mass no. less than 20,

there are some peaks in the BE graph corresponding to even-even number of proton, neutron such as He^4 , Be^8 , C^{12} , O^{16} etc.

(iii) nuclei having mass no. greater than 180 are naturally radioactive due to less binding energy per nucleon.

The nuclei with mass no. less than 30, can be easily converted to artificial radioactive nuclei, as the BE/A is less.

(*) Draw the neutron no. vs proton number graph for all the nuclei. Explain the stability of nucleus from this graph.



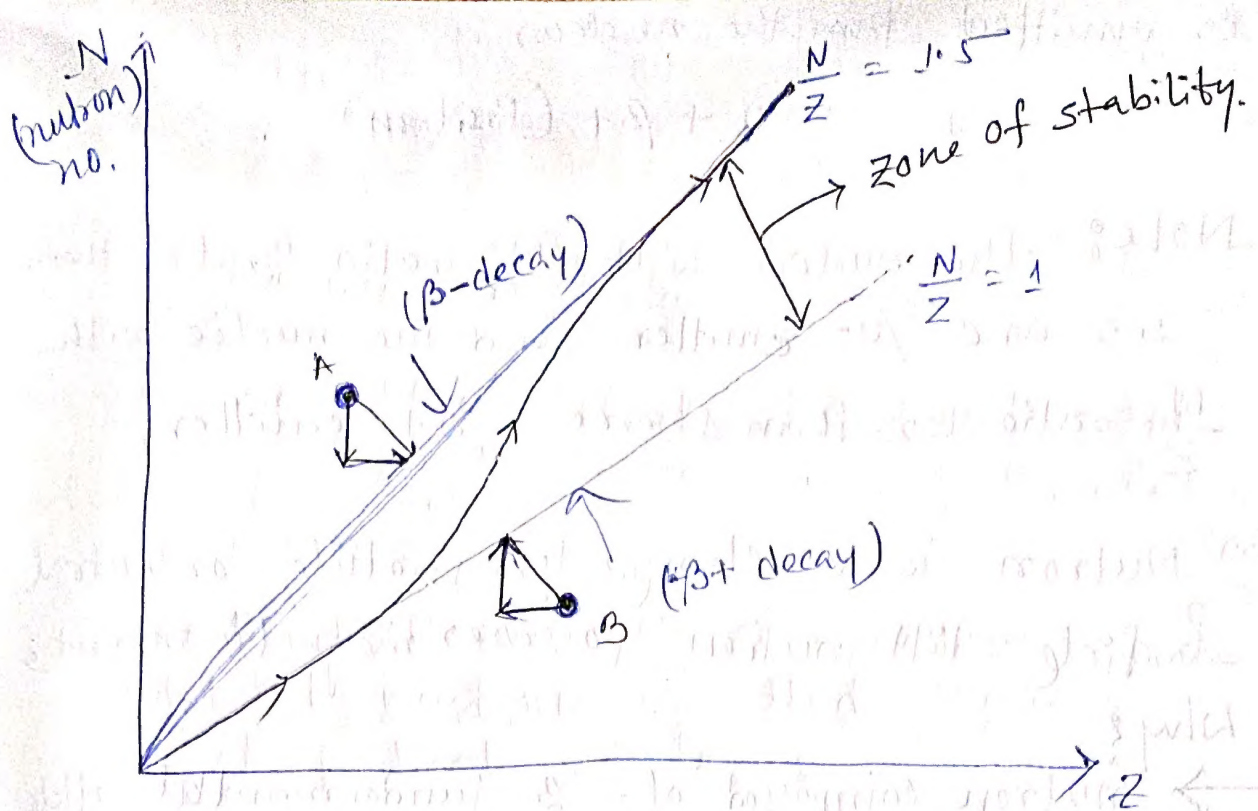
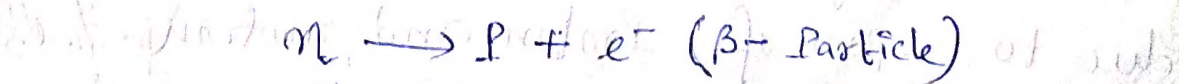


fig:- neutron no. vs Proton no. graph (Proton) no.

for lighter stable ~~st~~ nucleus like C, N, O, the N/Z ratio is 1 and for heavier stable nucleus like, Pb, Au, Pt the N/Z is 1.5.

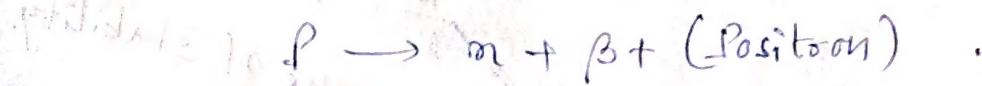
the N/Z graph for all the stable nucleus is inbetween $\frac{N}{Z} \geq 1$ and $\frac{N}{Z} \leq 1.5$ as shown in the figure this range $1 \leq \frac{N}{Z} \leq 1.5$ is known as zone of stability.

We consider a radioactive nuclei A with $\frac{N}{Z}$ ratio greater than 1.5. For the stability of this nucleus neutron is converted to proton when β^- / e^- is emitted from the nucleus.



Another radioactive nuclei with ~~more~~ $\frac{N}{Z}$ ratio less than 1. For the stability of this nucleus proton is converted to neutron and β^+ (positron)

is emitted from the nucleus.



Note:- the nuclei with N/Z ratio greater than 1.5 are β^- emitter and the nuclei with N/Z ratio less than 1 are β^+ emitter.

(*) Neutron is a chargeless particle or neutral particle. Still neutron possesses magnetic moment. Why?

→ Neutron composed of 3 fundamental particles
2-down quarks (charge: $-\frac{1}{3}e$) 1-up quarks (charge: $\frac{2}{3}e$).

As a whole neutron is chargeless but due to quark's particle neutron has magnetic moment.

(*) Write down the unit of magnetic moment of nucleus? Why nucleus possesses magnetic moment?

→ Nucleus is composed of protons and neutron, both proton and neutron has spin about their own axis. Proton is charge particle and neutron is composed of fundamental charge particle quarks and a magnetic moment is generated due to spin of proton and neutron. This is why nucleus possesses magnetic moment.

the unit of nuclear magnetic

moment is nuclear magneton (μ_N).

$$\mu_N = \frac{e\hbar}{2m_n} = 5.05 \times 10^{-27} \text{ J/Tesla}.$$

$$= 5.05 \times 10^{-27} \text{ Amp-m}^2 \quad \left| \begin{array}{l} m_n = \\ \text{mass of} \\ \text{neutron} \end{array} \right.$$

(*) why electric dipole moment of nucleus is always zero?

Nuclear Model's

* Write down the different features of nucleons that can be explain liquid drop model?

ii) write down the basic assumption's of liquid drop model's?

→ ii) Basic assumption's of liquid drop model

(i) in liquid drop model we consider a nucleon as a incompressible matter or liquid.

(ii) the nuclear force is identical for every nucleon

(iii) nuclear force saturate.

(iv) In an equilibrium state, the nuclei, of an atom remain spherically symmetric under the action of strong attractive nuclear force.

(i) similarity between nucleon and liquid drop model —

(i) the nuclear force is analogous to the surface tension force of a liquid.

(ii) the nucleon's behave in a manner similar to the molecule's in a liquid.

(iii) the density of nucleon is almost independent of mass number and the density is const.

this is similar to incompressible liquid drop.

(iv) the binding energy per nucleon is analogous to the latent heat of vapourisation.

(v) the disintegration of nuclei by the emission of particles is analogous to the vapourisation of the molecules from the surface of the liquid.

* Write down the limitations of liquid drop model.

→ (i) The liquid drop model fails to explain the high stability of nuclei with magic numbers

(ii) This model does not explain the measured spin and magnetic moment of the nuclei.

* Write down bethe - weizsacker mass formula, mentioning each term?

ii) Using liquid drop model derive bethe weizsacker mass formula or semi-empirical mass formula. (or)

→ Derive semi-empirical mass formula for Binding energy of nucleus. → Experimental.

→ According to semi-empirical mass formula for binding energy for a nucleus of mass no. A and atomic no. Z is given by,

$$BE = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_{as} \frac{(A-2Z)^2}{A} +$$

where,

$(0, \pm a_p A^{-3/4})$
 $a_v, a_s, a_c, a_{as}, a_p$ are coefficients related to, volume energy, surface energy, Coulomb energy, asymmetric energy, pairing energy.

(i) Volume energy term:-

Let, the interaction energy between two nucleons due to strong nuclear force = u .

for each nucleon interaction energy = $\frac{u}{2}$.

Due to high density of nucleus co-ordination no. = 12. (co-ordination no. = nearest nucleon no.)

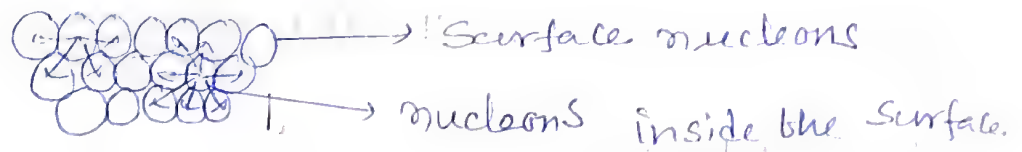
So, interacting energy generated by nucleon = $\frac{u}{2} \times 12$

For all the nucleons interaction energy = $6u$.
due to nuclear force = $6uA$.

this energy is known as volume energy term = $6uA$

$$E_v = a_v A \quad (a_v = \text{const.})$$

(ii) Surface energy term:-



The nucleons present on the surface do not contribute in volume energy term because, the force on this nucleons are not symmetric and the resultant nuclear force on this nucleons towards the core of the nucleus.

This symmetric force nuclear force tries to break the shape of the nucleus.

Surface area of a nucleus = $4\pi R^2$, R = radius of the nucleus.

the no. of nucleons on the surface \propto Surface area of the nucleus

Surface energy \propto surface area.

$$\propto -4\pi R^2$$

$$\propto -4\pi R_0^2 A^{2/3}$$

$$E_s = -a_s A^{2/3}$$

(c) Coulomb Energy term:

Due to the repulsive force between proton-proton binding energy decreases.

The Coulomb energy or potential energy generated due to repulsion of two protons

r = separation between two protons.

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{r}$$

for, Z no. of protons the no. of interactions

$$= \frac{Z(Z-1)}{2}$$

the total Coulomb energy, $= -\frac{1}{4\pi\epsilon_0} \frac{Z(Z-1)}{r_{av} \cdot 2}$

$$r_{av} \approx R = r_0 A^{1/3}$$

$$= -\frac{e^2}{8\pi\epsilon_0} \frac{Z(Z-1)}{r_0 A^{1/3}}$$

$$E_c = -a_c \frac{Z(Z-1)}{A^{1/3}}$$

(iv) Asymmetric Energy term

From the experimental data the stability of nucleus decreases with the increase in the difference between proton and neutron no. in a nucleus,

But, stability increases due to increasing mass no. [From volume energy term].

asymmetric energy term $E_{as} = -a_{as} \frac{(N-Z)^2}{A}$

$$E_{as} = -a_{as} \frac{(A-2Z)^2}{A}$$

(v) Pairing Energy term:-

The protons and neutrons of a nucleus form shells like structure similar to electrons.

The nucleus with even even no. of proton neutrons are more stable as compared to nucleus with odd-odd no. of proton-neutron.

From experimental data,

$$E_p = a_p A^{-3/4}, \text{ for even-even}$$

$$= -a_p A^{-3/4}, \text{ for odd, odd.}$$

$$= 0, \quad \begin{array}{l} \text{even-odd} \\ \text{odd-even} \end{array} / a_p = \text{const.}$$

* using semi-empirical mass formula find the atomic number of most stable isobar.
 → Isobar → same mass no. different atomic no.

from semi-empirical mass formula

$$BE = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_m \frac{(A-2Z)^2}{A} + \delta(A)$$

$$\frac{\partial BE}{\partial Z} = -\frac{a_c}{A^{1/3}} (2Z-1) + 4a_m \frac{(A-2Z)}{A}$$

$$1) 0 = -\frac{a_c}{A^{1/3}} (2Z-1) + 4a_m \frac{(A-2Z)}{A}$$

$$2) 0 = -\frac{2a_c Z}{A^{1/3}} + \frac{a_c}{A^{1/3}} + 4a_m - \frac{4a_m 2Z}{A}$$

$$3) Z \left(\frac{2a_c}{A^{1/3}} + \frac{8a_m}{A} \right) = \frac{a_c}{A^{1/3}} + 4a_m$$

$$4) Z = \frac{a_c A^{1/3} + 4a_m}{2a_c A^{-1/3} + 8a_m A^{-1}}$$

$$5) \boxed{Z = \frac{4a_m A + a_c A^{2/3}}{2a_c A^{1/3} + 8a_m}}$$

this is the expression for most stable isobar

(*) Using semi-empirical mass formula. Find the binding energy of (i) ${}_{20}^{40}\text{Ca}$, (ii) ${}_{19}^{39}\text{K}$

→ Given $a_v = 15.5 \text{ MeV}$, $a_s = 16.8 \text{ MeV}$, $a_c = 0.7 \text{ MeV}$
 $a_m = 23 \text{ MeV}$, $a_p = 34 \text{ MeV}$.

$$BE = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} + (0, \pm a_p) A^{-3/4} - \frac{a_m (A-2Z)^2}{A}$$

(i) $Z = 20$, $N = 20$, $A = 40$

Pairing energy, $\pm a_p$.

$$\begin{aligned} \therefore BE &= 15.5 \times 40 - 16.8 \times (40)^{2/3} - 0.7 \times \frac{20 \times 19}{(40)^{1/3}} + 34(40)^{-3/4} - 23 \times 0 \\ &= 620 - 16.8 \times 11.84 - 6.65 + \frac{34}{15.905} \\ &= 620 + 2.137 - 205.562 \\ &= \underline{\underline{416.575 \text{ MeV}}} \end{aligned}$$

(ii) $Z = 19$, $N = 20$, $A = 39$

Pairing energy = 0

$$\begin{aligned} \therefore BE &= 15.5 \times 39 - 16.8 \times (39)^{2/3} - 0.7 \times \frac{19 \times 18}{(39)^{1/3}} + 0 - \frac{23}{39} \\ &= 604.5 - 195.589 - 6.138 - 0.589 \\ &= \underline{\underline{402.184 \text{ MeV}}} \end{aligned}$$

(*) find the most stable isobar for mass number $A=56$.

$$a_v = 15.5 \text{ MeV}, a_s = 16.8 \text{ MeV}, a_c = 0.7 \text{ MeV},$$

$$a_{as} = 23 \text{ MeV}, a_p = 34 \text{ MeV}.$$

→ Atomic number for most stable isobar

$$Z = \frac{a_c A^{2/3} + 4a_{as}A}{2a_c A^{2/3} + 8a_{as}}$$

$$= \frac{0.7 \times (56)^{2/3} + 4 \times 23 \times 56}{2 \times 0.7 \times (56)^{2/3} + 8 \times 23}$$

$$= \frac{\quad}{\quad}$$

$$= 25.24$$

$$\approx 26 \quad \boxed{\begin{matrix} \text{Fe}^{56} \\ 26 \end{matrix}} \text{ is most stable isobar.}$$

Corresponding to mass no. 56.

write down the evidence of nuclear shell model.

(*) In nuclear shell model we consider that Protons, neutrons form their individual shells or orbit like structure similar to electron configuration.

For the closed shell of Proton and neutron, the nucleus is more stable compare to nucleus with half filled or less than half filled shell.

There are many physical Proves of nuclear shell model —

(i) Some nucleuses with particular.

no. of Proton and neutron is more stable, these numbers are known as magic no.

Magic no.'s are - 2, 8, 20, 50, 82, 126. This magic no.'s cannot be explain using liquid drop model.

(i) nucleus with magic no. proton's has high separation energy for proton as compared to other nucleuses in the neighbourhood.

(ii) nucleus with magic no. neutron's has high separation energy for neutron as compared to other nucleuses in the neighbourhood.

(iii) Proton capture cross section or Proton capture probability of a nucleus with magic no. proton's is very small as compared to neighbourhood nuclei. because the Proton shell is closed for this nucleus.

(iv) neutron capture cross section or neutron capture probability of a nucleus with magic no. neutron's is very small as compared to neighbourhood nuclei. because the neutron shell is closed for this nucleus.

(v) in liquid drop model it was consider that, the shape of the nucleus is spherical but in practical only the nucleuses with

magic no. proton and neutron has spherical shape, other nucleus has shape prolate and oblate.

- (*) Write down the advantages of nuclear shell model over liquid drop model?
- (*) (or) write down the limitations of nuclear shell model.

(*) Explain the origin of magic no's. with Mayer correction.

(or)
Explain how magic no's represent closed proton neutron shell.

(or)
with spin orbit interaction of proton neutron explain the magic no's,

(i) → Advantages of nuclear shell model :-

- (1) It explains very well the existence of magic numbers and the stability and high binding energy on the basis of closed shells.
- (2) The shell model provides explanation for the ground state spins and magnetic moments of the nuclei.
- (3) Nuclear isomerism, i.e. existence of isobaric, isotopic nuclei in different energy states of odd-A nuclei between 39-49, 69-81, 111-125 has been

explained with shell model.

i) → Limitations of nuclear shell model are:-

(1) The model does not predict the correct value of spin quantum numbers in certain nuclei. ex - $^{23}_{11}\text{Na}$ where the predicted value is $5/2$, the corrected value is $3/2$.

(2) The following four stable nuclei, ^2_1H , ^6_3Li , $^{10}_5\text{B}$, $^{14}_7\text{N}$ do not fit into this model.

(3) The model cannot explain the observed 1st excited states in even-even nuclei at energies much lower than those expected from single-particle excitation.

And also failed to explain the observed quadrupole moment of odd-A nuclei in particular of those having A-values far away from the magic number.

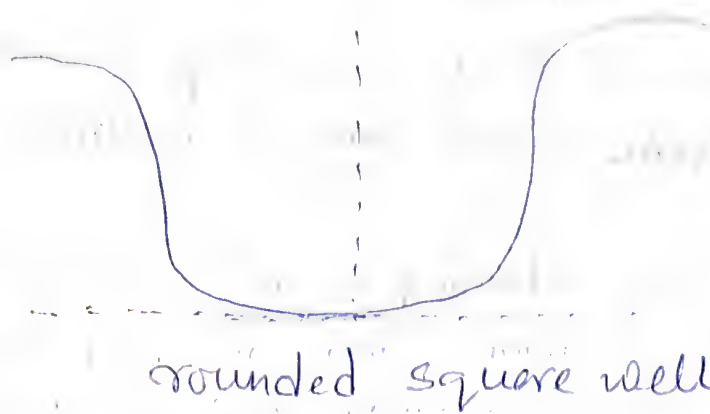
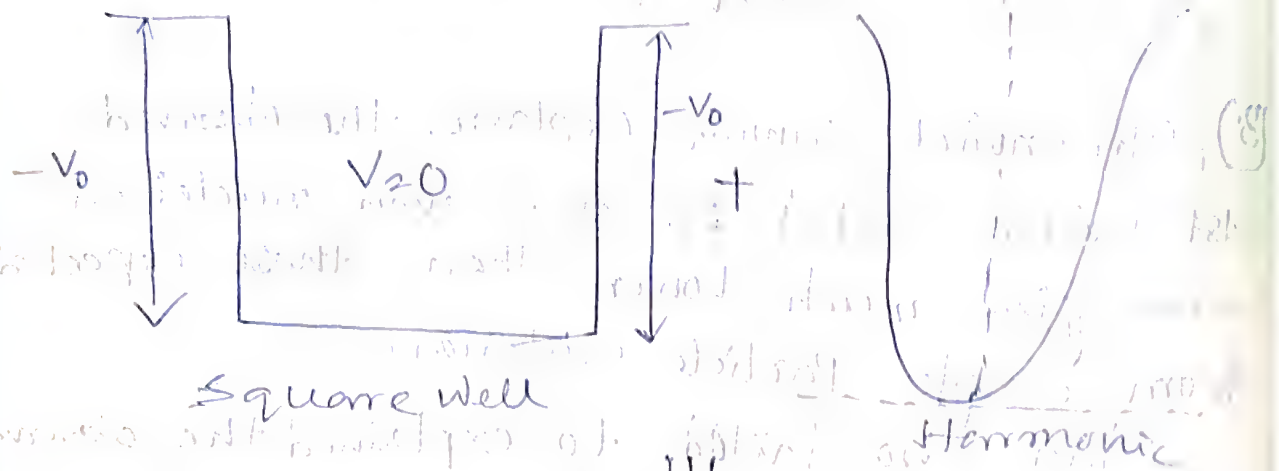
(5)* → By using Schrodinger eqⁿ we can describe the motion of nucleon and different energy level of nucleon in a nucleus. But we don't know the exact profile of nuclear potential energy.

(Corresponding to nuclear force)

So, we have to use the trial method for nuclear potential energy. Scientist try with different potential energy like square well potential, Harmonic potential, Wood-Saxon potential

$$V(r) = \frac{V_0}{1 + e^{(r-R)/a}}$$

Yukawa Potential $[V(r) = -V_0 e^{-\mu r}]$,
 rounded square well potential etc.
 -The best result was obtained by using
 rounded square well potential. rounded
 square well potential is a hybridised or
 potential of square well potential and harmonic
 potential. (2)



Using rounded square well potential in
 Schrodinger's eqⁿ we get the energy level
 of nucleon's, $E_\lambda = (\lambda + \frac{3}{2}) \hbar \omega$, where,

where, $n =$ quantum no. for
 square well potential $\lambda = 2n + l - 2$
 $l =$ quantum no. for
 isotropic harmonic potential. $n = 1, 2, 3, \dots$ $l = 0, 1, 2, 3, \dots$

λ	Energy level $E_\lambda = (\lambda + \frac{3}{2})\hbar\omega$	(n, l)	nl (state)	$2(2l+1)$ no. of nucleons	Magic no.
0	$\frac{3}{2}\hbar\omega$	(1, 0)	1s	2	2 ✓
1	$\frac{5}{2}\hbar\omega$	(1, 1)	1p	6	8 ✓
2	$\frac{7}{2}\hbar\omega$	(2, 0) (1, 2)	2s 1d	2 } 10 }	20
3	$\frac{9}{2}\hbar\omega$	(2, 1) (1, 3)	2p 1f	6 } 14 }	40

by using rounded square well potential we can explain the ^{only} magic no 2, 8, 20 only. Further magic no. can not be explained using rounded square well potential.

Mayer correction: Further Scientist Mayer and his research group suggested that there is a spin-orbit interaction of Proton and neutron similar to electron.

the spin-orbit interaction energy.

$$V(r) = -\phi(r) [\vec{L} \cdot \vec{S}] \quad \text{--- (1) } \phi(r) = \text{co-efficient}$$

total angular momentum

$$\vec{J} = \vec{L} + \vec{S}$$

$$J^2 = (\vec{L} + \vec{S}) \cdot (\vec{L} + \vec{S})$$

$$J^2 = L^2 + S^2 + 2\vec{L} \cdot \vec{S}$$

depends on
 r

\vec{L} = orbital angular momentum.

\vec{S} = spin angular momentum.

$$1) \vec{J}^2 - \vec{L}^2 - \vec{S}^2 = 2 \vec{L} \cdot \vec{S}$$

$$2) \vec{L} \cdot \vec{S} = \frac{\vec{J}^2 - \vec{L}^2 - \vec{S}^2}{2} \rightarrow (11)$$

Using equⁿ (11) in equⁿ (1),

$$V(r) = -\phi(r) \left[\frac{\vec{J}^2 - \vec{L}^2 - \vec{S}^2}{2} \right],$$

$$= -\phi(r) \frac{[\vec{J}(\vec{J}+1) - l(l+1) - s(s+1)] \hbar^2}{2}$$

$$\vec{J} = \sqrt{\vec{J}(\vec{J}+1)} \hbar$$

$$\vec{L} = \sqrt{l(l+1)} \hbar$$

$$\vec{S} = \sqrt{s(s+1)} \hbar$$

We know that,

$$\vec{J} = |l+s| \dots \dots \dots |l-s|$$

$$\therefore \vec{J} = l + \frac{1}{2}, l - \frac{1}{2} \quad \text{for Proton, neutron}$$

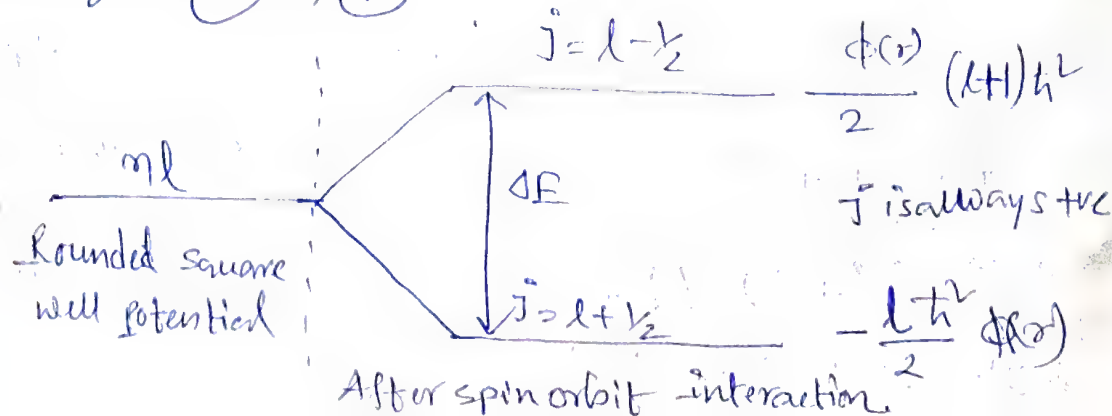
$$\text{for, } \vec{J} = l + \frac{1}{2}, s = \frac{1}{2}$$

$$V(r) = -\frac{l \hbar^2}{2} \phi(r) \rightarrow (1v)$$

$$\text{for, } \vec{J} = l - \frac{1}{2}, s = \frac{1}{2};$$

$$V(r) = \frac{\phi(r)}{2} (l+1) \hbar^2 \rightarrow (v)$$

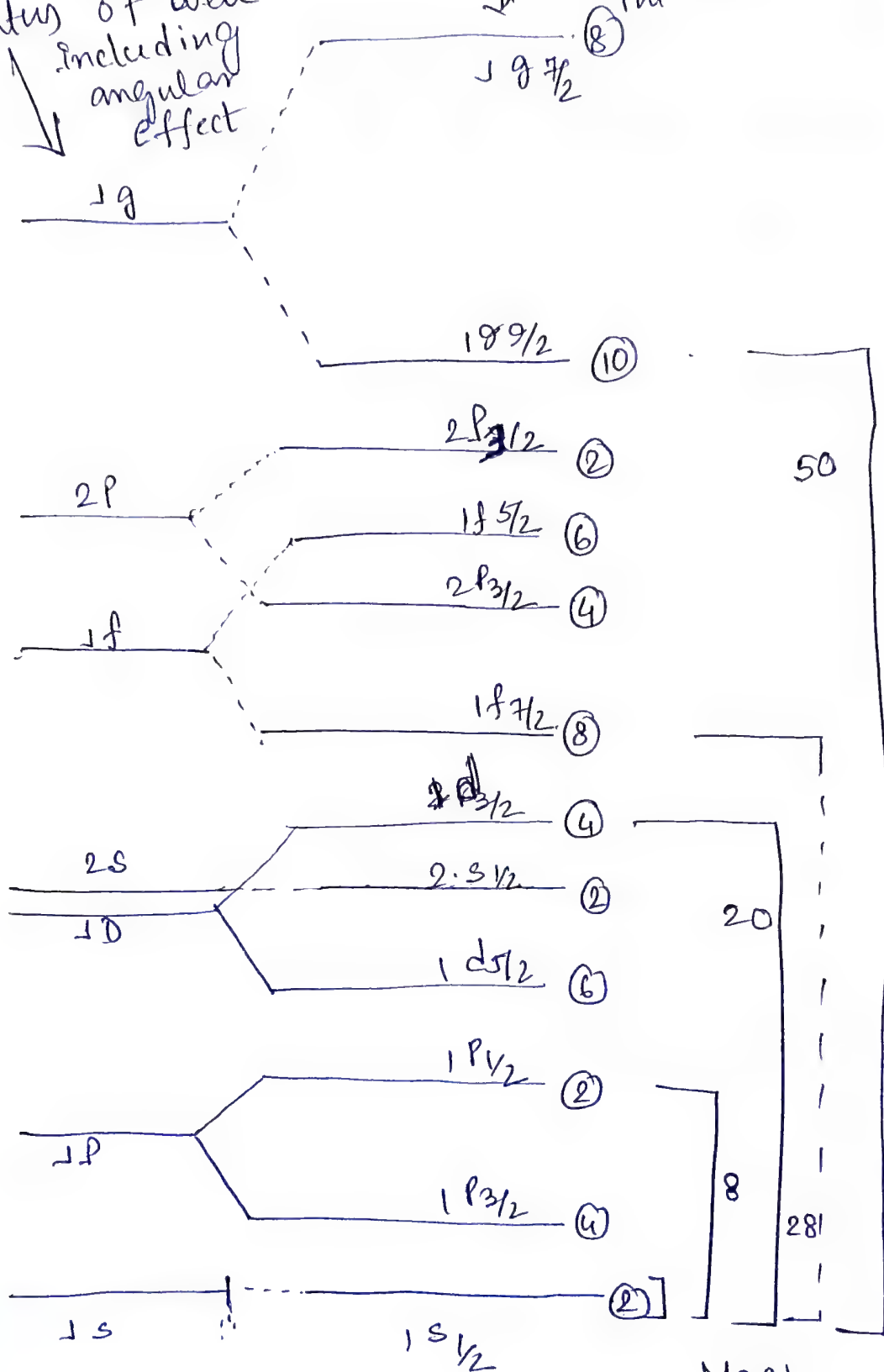
from equⁿ (iv), (v)



Energy level diagram of shell model after Mayer correction & Further splitting from spin-orbit interaction.

Quantum energy status of well including angular effect

Multiplicity of state.



S.H.O

S.H.O +
Orbit interaction.

Magic no.

Application of shell model :-

By using shell model we can find the Spin Parity of a nucleus.

Case-I. nucleus with even even no. of proton-neutron, In this case there is no unpaired, proton and or neutron, that is why the spin of the nucleus is always zero and Parity is '+' because they are in Paired form.

$$\text{Spin Parity} = \frac{1}{2}^{\pi} = 0^{+}$$

Case-II nucleus with Odd-no. of Proton and even no. of neutron ~~or~~ odd no. neutron and even no. of Proton, in this case the spin of the nucleus is the 'j'-value of last unpaired proton/neutron the Parity of the state = $(-1)^l$; where l = orbital quantum number of last unpaired Proton/neutron.

Case-III. nucleus with odd-odd no. of Proton and neutron, In this case, there will be one unpaired proton and one unpaired neutron. for the unpaired Proton the last energy level = l_p, j_p

for the unpaired neutron the last
Energy level = l_n, j_n

the spin of the nucleus is given by

- Nordheim rules

$$\text{if } |l_p + j_p + l_n + j_n| = \text{even}$$

$$\text{the spin of the nucleus } j = |j_p - j_n|$$

$$\text{if } |l_p + j_p + l_n + j_n| = \text{odd}$$

$$\text{the spin of the nucleus } j = |j_p + j_n|$$

$$\text{Parity} = (-1)^{l_p + l_n}$$

Find the spin parity of following
nucleuses:- (i) C^{12} , (ii) K^{39} , (iii) F^{18}
(iv) K^{40}

→ (i) C^{12}
 6 12
 6 6
 $n = 6$

as there is even-even no. of Proton
and neutron, spin-parity = 0+

(ii) K^{39}
 19 39
 19 20
 $n = 20$

$$(1s_{1/2})^2 (1p_{3/2})^4 (1p_{1/2})^2 (1d_{5/2})^6 (2s_{1/2})^2 (1d_{3/2})^3$$

for, unpaired proton, $j = 3/2$, $l = 2$

$$\text{Parity} = (-1)^l = (-1)^2 = +1$$

Spin-Parity of this nucleus = $3/2^+$

(iii) F^{18} , $Z=9$
 9 $n=9$.

for neutron, $(1s_{1/2})^2 (1p_{3/2})^4 (1p_{1/2})^2 (1d_{5/2})^1$

$J_n = 5/2$, $l_n = 2$.

for proton, $(1s_{1/2})^2 (1p_{3/2})^4 (1p_{1/2})^2 (1d_{5/2})^1$

$J_p = 5/2$, $l_p = 2$

using Nordheim rule,

$|J_p + J_n + l_p + l_n| = |5/2 + 2 + 5/2 + 2|$

= 9 odd.

\therefore the spin of nucleus = $J = 5$

Parity = $(-1)^{l_p + l_n} = +1$

\therefore Spin-Parity of nucleus = 5^+

(iv) K^{40} , $Z=19$
 19 $n=20$.

for proton, $(1s_{1/2})^2 (1p_{3/2})^4 (1p_{1/2})^2 (1d_{5/2})^6 (2s_{1/2})^2 (2d_{3/2})^3$

for neutron, $J_n = 3/2$, $l_n = 2$.

$(1s_{1/2})^2 (1p_{3/2})^4 (1p_{1/2})^2 (1d_{5/2})^6 (2s_{1/2})^2 (2d_{3/2})^4 (1f_{7/2})^1$

$$I_n = 7/2, \quad l_n = 3.$$

Using Nordheim rule,

$$|I_p + I_n + l_n + I_n| = 10 \quad \text{even}$$

$$\therefore J = |-2| = 2$$

$$\therefore \text{parity} = (-1)^J = -1$$

$$\therefore \text{spin-parity of nucleus} = 2^- \quad \underline{\text{Ans}}$$

⊛ What do you mean by "Mean field theory" nucleus?

⊛ Explain "Mean field theory"

→ In atom the electrons are revolving around the nucleus due to electrostatic interaction between the nucleus and electrons.

But in case of proton and neutron's in nucleus, there is no such centre about which the proton and ~~the~~ neutron can revolve. Scientists assumed that the proton and neutron's experience's some nuclear force, which is the average of nuclear force of the whole nucleus (for 1 nucleon) and they revolve around this mean force field of nuclear force.

In this condition, we can describe the nature of whole nucleus by one nucleon only
 as ~~the~~ each of the nucleon experiences

Same force. This is known as "mean field theory" of nucleus.

Mean field theory is used in single particle shell model.

* Write down the assumption of Fermi gas model of nucleus. Write down its merits and limitations.

→ Fermi gas Model

assumption so

- (1) All Fermion's Occupy the lowest energy states.
- (2) Protons and neutron's are independent fermion filling two separate potential wells.
- (3) Common Fermi energy for proton's and neutron's in stable nuclei.

(iii) ① → Packing fraction - The ratio of the mass defect (mass difference between individual mass and ~~total~~ mass of nucleus) and the mass number of a nuclei is known as Packing fraction.

② → mass defect - The difference in mass ~~and~~ of a nucleus and its constituent nucleon is called the mass defect of that nucleus.

③ ④ ⑤ → The names of various models of the nucleus is given by —

- (i) liquid drop model.
- (ii) shell model.
- (iii) ^{nuclear} compound nucleus model.
- (iv) Fermi gas model of nucleus.

⑥ → Because, As the no. of Proton increases in a nucleus, the coulomb's repulsive force increases, which tends to break the nucleus apart. So, to keep the nucleus stable, more no. of neutrons are needed, which are neutral in nature.

⑦ → ~~For~~ The liquid drop model admits only a nuclear surface and interior. In contrast, shell models predicts energy shell and subshells, and therefore admit rich internal ~~substructure~~ substructure.

⑧ → For the stability of nucleus some times neutron's are converted to proton and some times proton converted to neutron, when β -particle emits from the nucleus.

... contribution over cyclotron is

(9) \rightarrow As the thickness of the material is increased, the fraction of the radiation passing through the material will decrease.

(10) \rightarrow Particle accelerator is a device used to accelerate different charge particles to high velocity or high KE, which is necessary for many nuclear reactions or experiments.

No, we can't accelerate neutrons by cyclotron.

(11) \rightarrow (i) Initial energy of α particle.

(ii) The range of α particle inversely proportional to the ionization energy of the gas.

(iii) ~~The~~ range of α particle is inversely proportional to density of the medium.

(iv) The range of α particle proportional to temperature and inversely proportional to ~~temp~~, pressure.

(13) \rightarrow Isospin is an abstract quantity, it is not physical quantity. In strong interaction between two particles is independent of charge. To distinguish between neutron-proton we consider a quantum no. which is known as isospin.

(12) \rightarrow Cherenkov radiation is a form of energy that we can perceive as a blue glow emitted when the electrically charged particles that compose atoms, are moving at speeds faster than that of light in a specific medium.

(14) \rightarrow The angular momentum of the nucleus is the combined contribution of the spin-orbit angular momenta of the constituent particles.